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Hydrobiological analysis of a peat bog with emphasis on its planktonic diversity and population dynamics in Bumdeling Wildlife Sanctuary, eastern Bhutan

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Abstract A pioneering limnological investigation was carried out in Bhutan in a small peat bog in the Trashiyangtse district (1950m above sea level) from February 2000 to January 2002. The sampled pond water had low transparency (55.0–95.0cm), was typically acidic (pH 5.69–6.58) with soft water (alkalinity, 11.0–36.0mg/l; total hardness, 10.0–34.0mg/l), and had low to moderate specific conductivity (17.0–62.0µS/cm). Further, moderate Na (2.0–6.8mg/l), K (1.8–13.5mg/l), sulphate (0.85–2.99mg/l), and silicate (2.5–15.0mg/l) concentrations as well as low nutrient levels such as phosphate (0.006–0.170mg/l) and nitrate (0.003–0.180mg/l) characterize the water in the peat bog. The recorded net plankton comprised 27 species of phytoplankton and 49 species of zooplankton, with the latter indicating greater homogeneity and breaking down into Rotifera (23 species) > Cladocera (13 species) > Rhizopoda (8 species) > Copepoda (3 species) > Ostracoda = Nematoda (1 species each). On the other hand, the net plankton density ranged between 93 and 692 number/l (n/l) with numerical dominance by phytoplankton (68.5% ± 12%), of which Chlorophyceae were predominant (90 ± 63n/l). Zooplankton showed moderately high diversity (2.745 ± 0.293) and evenness (0.925 ± 0.049) and exhibited almost equal abundance of four recorded groups, namely Cladocera (20 ± 15n/l) > Rotifera (15 ± 6n/l) > Copepoda (14 ± 7n/l) > Rhizopoda (14 ± 4n/l). While no significant impact of abiotic factors was recorded on zooplankton density, rainfall alone was the most important factor that influenced net plankton and various groups of phytoplankton. Comments on some comparative limnological attributes are also made with similar as well as different habitats in the nearby Himalayan countries.

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Introduction

Bhutan, a far eastern Himalayan kingdom, is recognized as one of the global hotspots for conservation of biological diversity, with 35% of the country's total geographical area in diverse protected ecological zones (Anon 2004). Of these, Bumdeling Wildlife Sanctuary (1487km^2), in eastern Bhutan, besides comprising significant forest reserves, has several standing bodies of water, including high-altitude glacial lakes, ponds, paddy fields and wetlands. The selected study area is a small peat bog located within the main Bumdeling valley.

Peat bogs are mossy, peat-covered or peat-filled wetlands (peat land) that develop on open terrain with restricted drainage. The water supply of a bog comes almost exclusively from precipitation, resulting in a nutrient-poor, acidic environment (Horne and Goldman 1994). As a bog has limited external drainage, the surface is frequently covered with small ponds. Bogs, which are also called muskeg in Canada and Alaska and moors, mosses, and mires in Europe, are in a process of succession with continuous rising of the surfaces and with the establishment of "dry bog," which eventually gives rise to terrestrial systems in which a variety of vascular plants can begin to grow (Horne and Goldman 1994). The limnology of this unique lentic system, in spite of possessing interesting ecological attributes, is poorly understood worldwide.

In the light of the above lacunae and the ecological importance of peat bog in general, and also because of the absence of any limnological reports from Bhutan, the present study of a small peat bog in eastern Bhutan carries special significance. This report deals with temporal variations in physicochemical parameters; the composition of planktonic communities; and their synecology, richness, diversity, succession, and other related ecological attributes.

Study site

The study site is a small lowland peat bog located in Bumdeling valley (1950 m above sea level) in the Trashiyangtse District (91°27′23″ E; 27°39′53′ N) in eastern Bhutan and consists mainly of mats of moss (*Sphagnum* sp.). It has an area of 0.6 ha with several small ponds interspersed with a few trees, including *Rhododendron* sp., *Quercus* sp., and *Pinus* sp. on the thick mat of sphagnum. However, there is luxuriant growth of *Acorus calamus*, *Fallopia convolvulus*, *Gaultheria* sp., *Lindernia* sp., *Lyonia ovalifolia*, *Lycopodium* sp., *Pogostemon linearis*, *Polygonum* sp., and *Scirpus mucronatus* on the sphagnum as well as around the fringes of the bog. The pond that was sampled was about 3 m in depth with luxuriant growth of filamentous algae and decomposing moss.

Methods

Water samples as well as qualitative and quantitative plankton samples were collected for two annual cycles at monthly intervals between February 2000 and January 2002. Air and water temperatures were recorded using a centigrade thermometer. pH and specific conductivity were measured with a pH and conductivity meter, respectively, and transparency was assessed by Secchi disc. Dissolved oxygen was estimated by modified Winkler's method and other mentioned chemical parameters were analyzed by following A.P.H.A. (1992), which involved standard titration methods to determine free CO_2, total alkalinity, total hardness, Ca, Mg, and dissolved organic matter. While the other components, namely phosphate, nitrate, sulphate, and silica were determined spectrophotometrically, total dissolved solids were estimated by evaporation of a measured water sample. The rainfall data was obtained from Bumdeling Wildlife Sanctuary, park office, Trashiyangtse. All the plankton samples were collected using a nylobolt plankton net (No. #25) and preserved in 5% formalin in the field. Qualitative samples were obtained by towing the plankton net in the pond and quantitative samples were collected by filtering 25 l of water into a 25-ml tube (1 ml for each liter). Both types of samples were collected in triplicate every month. After identifying the phytoplankton to the generic level and zooplankton mostly to species status with qualitative samples, quantitative enumeration was done using a Sedgwick–Rafter counting cell by counting all planktonic communities in 1 ml of concentrated sample under a binocular microscope. At least three such counts were made for each sample and results were averaged to ascertain the numerical density of each organism.

Percentage similarities between various planktonic communities were calculated using Sorensen's index (Sorensen 1948). For the zooplankton, species, diversity was calculated by following Shannon's index (Ludwig and Reynolds 1988), species dominance was calculated using Simpson's index (Ludwig and Reynolds 1988), and evenness was assessed as E_1. Analysis of variance (ANOVA) was applied to ascertain the significance in variations in the recorded abiotic and biotic parameters between months and for two annual cycles of the study period. Ecological relationships were computed among abiotic and biotic factors and between abiotic and biotic factors by simple correlation coefficients (r). Statistical significance of the stated correlations was ascertained by application of student's t test.

Results and discussion

Abiotic parameters

Monthly physicochemical parameters are presented in Table 1. Air and water temperatures ranged between 10.5° and 28.8°C (18.2° ± 5.0°C) and between 9.1° and 26.0°C (16.4° ± 4.9°C) respectively, which denotes the subtropical nature of the sampled biotope. ANOVA indicated significant monthly variations in temperature ($F_{11,23} = 11.917$, $P < 0.01$), but these were not significant ($P > 0.05$) between the two study years. Similarly, monthly rainfall ranged between 5.0 and 225.0 mm (100.4 ± 84.0 mm) with marginally higher annual rainfall during the first year of study (1250.0 mm) compared to the second year (1160.4 mm). Further, the major volume of rainfall fell between May and September with generally dry winters during the study period. ANOVA also indicated significant monthly variations in rainfall ($F_{11,23} = 11.769$, $P < 0.01$). Rainfall exerted an inverse influence on transparency ($r = -0.660$) as a result of increased runoff rich in soil and debris entering the peat bog during the rainy season.

The penetration of light into the sampled peat bog was remarkably low (79.5 ± 12.7 cm) as a result of the shading

Table 1. Temporal variations of physicochemical parameters (Feb 2000 to Jan 2002)

Parameters	Range	Mean ± SD
Air temperature (°C)	10.5–28.8	18.2 ± 5.0
Water temperature (°C)	9.1–26.0	16.4 ± 4.9
Rainfall[a] (mm)	5.0–225.0	100.4 ± 84.0
Secchi disk transparency (cm)	55.0–95.0	79.5 ± 12.7
pH	5.69–6.58	6.17 ± 0.27
Specific conductivity (µS/cm)	17.0–62.0	42.4 ± 14.8
Dissolved oxygen (mg/l)	1.2–9.6	3.4 ± 1.8
Free carbon dioxide (mg/l)	11.2–65.0	19.5 ± 11.1
Total alkalinity (mg/l)	11.0–36.0	22.2 ± 7.8
Total hardness (mg/l)	10.0–34.0	18.3 ± 5.7
Calcium (mg/l)	3.2–8.4	5.6 ± 1.6
Magnesium (mg/l)	1.1–8.1	3.2 ± 1.5
Sodium (mg/l)	2.0–6.8	4.0 ± 1.5
Potassium (mg/l)	1.8–13.5	5.3 ± 3.4
Chloride (mg/l)	2.8–6.2	4.7 ± 0.9
Nitrate (mg/l)	0.003–0.180	0.100 ± 0.040
Phosphate (mg/l)	0.006–0.170	0.05 ± 0.05
Sulphate (mg/l)	0.85–2.99	1.59 ± 0.69
Silicate (mg/l)	2.5–15.0	8.6 ± 3.6
Dissolved organic matter (mg/l)	0.9–9.6	4.1 ± 3.1
Total dissolved solids (mg/l)	0.22–0.85	0.54 ± 0.17

[a] Source, Bumdeling Wildlife Sanctuary, park office, Trashiyangtse

effect of surrounding vegetation as well as the suspension of filamentous algae in the sampled pond. Comparatively higher transparency was recorded during the winter. ANOVA indicated significant variations in light penetration between months ($F_{11,23} = 3.198$, $P < 0.01$) but not between years ($P > 0.05$). The acidic nature of the peat bog (Horne and Goldman 1994) was affirmed by the low recorded pH, which ranged between 5.69 and 6.58 (6.17 ± 0.27) and also concurred with the report on the Nartiang peat bog (Lyngdoh 1998) in Meghalaya, a far eastern Himalayan state of India. Significant monthly variations in pH were observed ($F_{11,23} = 6.906$, $P < 0.01$) with a further drop in pH during the premonsoon period during both annual cycles of the study period. Similarly, the ionic concentration of the studied biotope was generally low (42.4 ± 14.8 µS/cm) and exhibited annual maxima in early summer and minima during the monsoon, indicating the dilution effect of the rainwater. ANOVA also indicated significant monthly variation in the specific conductivity ($F_{11,23} = 24.489$, $P < 0.01$). The recorded values closely resembled those of most lentic waters of Meghalaya (Sharma 2001) as well as those found in a lake in Sikkim (Jain et al. 1999) and a subtropical lake in Nepal (Swar and Fernando 1979). However, specific conductivity is considerably lower than reports from the western Himalayas (Pandit 1999; Sarwar 1999). The relatively low dissolved oxygen concentration of the sampled water (3.4 ± 1.8 mg/l) was similar to that for Nartiang peatbog (Lyngdoh 1998), which could be attributed to greater utilization of oxygen in the decomposition of debris. On the other hand, high free carbon dioxide levels were recorded which ranged widely between 11.2 and 65.0 mg/l (19.5 ± 11.1 mg/l), thereby reflecting its poor autotrophic uptake in this ecosystem.

The values for total alkalinity (22.2 ± 7.8 mg/l) as well as total hardness (18.3 ± 5.7 mg/l) denoted the soft water nature of the studied biotope, with still lower values during the monsoon caused by the dilution effect of the rainwater. These results concurred with earlier reports from the western Himalayas (Singh et al. 1982; Quadri and Yousuf 1988; Pandit 1999; Sarwar 1999). Significant variations occurred in total hardness between the two years of study ($F_{1,11} = 5.810$, $P < 0.05$), with higher values during the second year (20.3 ± 6.0 mg/l) compared to first year (16.3 ± 4.8 mg/l) with a peak in February. In addition, low Ca (5.6 ± 1.6 mg/l) and Mg (3.2 ± 1.5 mg/l) levels further affirmed the soft water characteristics of the studied water body. The sampled water also showed low Na levels (4.0 ± 1.5 mg/l) and a moderate content of K (5.3 ± 3.4 mg/l). Similarly, low chloride levels (4.7 ± 0.9 mg/l) indicated the absence of organic pollution in the pond.

The peat bog is nutritionally poor as shown by low nitrate (0.10 ± 0.04 mg/l), low phosphate (0.05 ± 0.05 mg/l), as well as low sulphate (1.59 ± 0.69 mg/l) levels. While no significant annual or monthly variations were recorded in sulphate levels, ANOVA indicated significant variations in phosphate levels between months ($F_{11,23} = 3.520$, $P < 0.05$) as well as between the two years ($F_{1,11} = 7.254$, $P < 0.01$). A moderate quantity of silicate was recorded, ranging between 2.5 and 15.0 mg/l (8.6 ± 3.6 mg/l), which is higher than earlier reports of Dhendup and Boyd (1994), with regard to southern parts of Bhutan, and Sharma (2001), Zutshi et al. (1980), Negi and Pant (1983), and Sarwar (1999) with regard to various standing waters in the Himalayas. In addition, ANOVA indicated significant annual variations ($F_{11,23} = 6.993$, $P < 0.01$) in silicate content, with comparatively lower values during the first year (7.2 ± 3.2 mg/l) compared to second year (8.6 ± 3.5 mg/l). Dissolved organic matter ranged between 0.9 and 9.6 mg/l (4.1 ± 3.1 mg/l) with slightly higher values during the dry winter months as a result of reduced water level and subsequent concentration of the organic matter. ANOVA also indicated significant monthly ($F_{11,23} = 11.740$, $P < 0.01$) as well as annual ($F_{1,11} = 4.179$, $P < 0.05$) variations in dissolved organic matter. Organic matter levels indicated a positive relationship with silicate ($r = 0.509$) and nitrate ($r = 0.701$). Total dissolved solids, though were generally low (0.54 ± 0.17 mg/l), fluctuated with levels comparatively higher in winter and early summer.

Species composition of plankton

Net plankton comprised 27 species of phytoplankton and 49 species of zooplankton. Monthly species richness of net plankton varied relatively widely between 17 and 45 species (30 ± 7 species) with a bimodal pattern of temporal variations. Higher net plankton richness was observed during early summer with a peak in July. A second maxima of relatively low magnitude was also registered during midwinter. However, ANOVA indicated no significant variations of net plankton or phytoplankton species richness between sampled months ($P > 0.05$) or between the two study years ($P > 0.05$). Further, phytoplankton species richness was relatively low (10 ± 3 species) and included five groups (Table 2): Chlorophyceae (11 species) > Bacillariophyceae (7 species) > Cyanophyceae (5 species) > Euglenophyceae = Dinophyceae (2 species each). Of the Cholorophyceae, 7 species of desmids (64%) were recorded owing to low bicarbonate and Ca levels (Strom 1921; Hutchinson et al. 1932; Cole 1957; Wade 1957; Woelkerling and Gough 1976; Moss 1988). *Spirogyra* sp. was the most common filamentous algae recorded throughout the study

Table 2. Species composition of phytoplankton

Chlorophyceae
Closterium sp.
Closterium setaceum *Ehrenberg*
Cosmarium sp.
Desmidium sp.
Euastrum sp.
Pleurodiscus sp.
Pleurotaenium sp.
Netrium sp.
Pediastrum sp.
Spirogyra sp.
Ulothrix sp.
Bacillariophyceae
Caloneis sp.
Cymbella sp.
Eunotia sp.
Fragilaria sp.
Navicula sp.
Pinnularia sp.
Synedra sp.
Cyanophyceae
Anabena sp.
Lyngbya sp.
Microcystis sp.
Oscillatoria sp.
Phormidium sp.
Euglenophyceae
Euglena sp.
Euglena acus Ehrenberg
Dinophycea
Ceratium sp.
Glenodinium sp.

Table 3. Species composition of zooplankton

Rhizopoda
Actinosphaerium sp.
Arcella discoides Ehrenberg
A. megastoma Penard
Centropyxis aculeata (Ehrenberg) Stein
C. ecornis (Ehrenberg) Leidy
Difflugia sp.
D. lebes Penard
Euglypha sp.
Rotifera
Anuraeopsis fissa Gosse
Conochilus sp.
Colurella obtusa Gosse
Dicranophorous sp.
Epiphanes sp.
Euchlanis dilatata Ehrenberg
Lecane aculeata Jakubski
L. bulla Gosse
L. closterocerca Schmarda
L. doryssa Harring
L. hamata Stokes
L. inermis Bryce
L. luna Müller
L. lunaris Ehrenberg
Lepadella ovalis Müller
L. patella O.F. Müller
Macrochaetus sericus Thorpe
Monommata longiseta Müller
Philodina sp.
Trichocerca cylindrica Inshof
T. longiseta Schrank
T. pusilla Lauterborn
Trichotria tetractis Ehrenberg
Cladocera
Diaphanosoma excisum Sars
Daphniopsis sp.
Ceriodaphnia cornuta Sars
Simocephalus serrulatus Koch
Moina micrura Kurz
Pleuroxus similis Vavra
Chydorus sphaericus O.F. Müller
Alona costata Sars
A. guttata Sars
A. monocantha Stingelin
A. rectangula Sars
Macrothrix laticornis Jurine
Biapertura karua King
Copepoda
Tropocyclops sp.
Eucyclops sp.
Diaptomus sp.
Ostracoda
Cypris sp.
Nematoda species

Table 4. Temporal variations (Feb 2000 to Jan 2002) of planktonic characteristics

Biotic factors /features	Range, mean, and SD
Net Plankton (n/l)	93–692 (245 ± 136)
Phytoplankton	
Species richness	5–16 (10 ± 3)
Community similarity (%)	13.3–95.2
Abundance (cells/l)	55–630 (179 ± 136)
Percentage composition (%)	35.3–91.0 (68.5 ± 12.0)
Shannon's diversity index	0.961–2.882 (2.046 ± 0.590)
Simpson's dominance index	0.128–0.666 (0.290 ± 0.145)
Evenness	0.536–1.386 (0.908 ± 0.240)
Chlorophyceae (cells/l)	15–274 (90 ± 63)
Bacillariophyceae (cells/l)	2–226 (36 ± 34)
Cyanophyceae (cells/l)	2–335 (49 ± 77)
Euglenophyceae (cells/l)	0–9 (5 ± 2)
Dinophyceae (cells/l)	0–6 (4 ± 2)
Zooplankton	
Species richness	12–29 (20 ± 5)
Community similarity (%)	23.5–91.9
Abundance (n/l)	34–123 (66 ± 20)
Percentage composition (%)	10.4–64.7 (31.5 ± 12.02)
Shannon's diversity index	1.871–3.240 (2.745 ± 0.293)
Simpson's dominance index	0.037–0.267 (0.074 ± 0.045)
Evenness	0.729–0.967 (0.925 ± 0.049)
Rotifera (n/l)	5–30 (15 ± 6)
Cladocera (n/l)	6–80 (20 ± 15)
Copepoda (n/l)	4–33 (14 ± 7)
Rhizopoda (n/l)	4–32 (14 ± 7)
Ostracoda (n/l)	0–3 (2 ± 1)
Nematoda (n/l)	0–4 (2 ± 1)

period. In addition, the phytoplankton community exhibited heterogeneity in its structure (13.3%–95.2%).

On the other hand, zooplankton species richness ranged relatively wider than for phytoplankton, i.e., 12–29 species (20 ± 5 species), with greater richness during summer. However, ANOVA indicated no significant variations of zooplankton richness between sampled months ($P > 0.05$) or between the two studied years ($P > 0.05$). Although the recorded values are identical to some reports from Kashmir (Yousuf and Quadri 1985; Balkhi et al. 1987), they are lower than the report of Pandit (1999) in that part of the Himalayas. On the other hand, the recorded richness is higher than those reported from Meghlaya (Sharma 1995; Jyrwa 1996; Sharma and Lyngdoh 2003). The present composition of zooplankton comprised Rotifera (23 species) > Cladocera (13 species) > Rhizopoda (8 Species) > Copepoda (3 Species) > Ostracoda = Nematoda (1 species). Of the rotifers, 8 were species of lecanids (Table 3), including the acidophilic *Lecane doryssa*, which was representative of the acidophilic element of the sampled peat bog fauna. In addition, the sampled bog did not show any of the generally alkalophilic brachionids. Community similarities ranged between 23.5% and 91.9%, with 73% of the instances showing greater than 50% community similarity, thereby indicating homogeneity in the zooplankton community in this ecosystem.

Abundance of plankton

Net plankton density fluctuated with notable temporal variations between 93 and 692 n/l (245 ± 136 n/l) and indicated generally higher density during the midmonsoon period (July–August), which was also affirmed by a positive correlation with rainfall ($r = 0.579$). Significant annual variations of net plankton abundance ($F_{1,11} = 4.812$, $P < 0.05$) was recorded with a relatively higher abundance noted during the second annual cycle as a result of higher phytoplankton abundance compared to the first year. Phytoplankton abundance ranged widely between 55 and 630 n/l (179 ± 136 n/l) and was directly influenced by the monsoon, as affirmed by its positive correlation with rainfall ($r = 0.535$), which also corroborated the reports of Zutshi et al. (1980).

Further, the abundance of the five groups of recorded phytoplankton in this water body were Chlorophyceae (90 ± 63 cells/l) > Cyanophyceae (49 ± 77 cells/l) > Bacillariophyceae (36 ± 43 cells/l) > Euglenophyceae (5 ± 2 cells/l) > Dinophyceae (4 ± 2 cells/l). Numerically, Chlorophyceae was the dominant group (5.6%–82.7%), mainly comprising *Spirogyra* sp. (10–158 cells/l) and *Ulothrix* sp. (0–153 cells/l). On the other hand, Cyanophyceae was recorded in high abundance in August (53.2%) and mostly consisted of *Lyngbya* sp., whereas the predominant Bacillariophyceae in winter (84.3%) mostly consisted of *Pinnularia* sp.

The quantitative abundance of zooplankton ranged between 34 and 123 n/l (66 ± 20 n/l) and was consistent during the first year, except for a marginal increase between March and June (75 ± 3 n/l). On the other hand, during the second year, the monthly abundance exhibited a unimodal pattern of temporal variations with maxima in spring. ANOVA also exhibited significant monthly variations ($F_{11,23} = 2.890$, $P < 0.05$) but no significant annual variations ($P > 0.05$). Zooplankton abundance was Cladocera (20 ± 15 n/l) > Rotifera (15 ± 6 n/l) > Copepoda (14 ± 7 n/l) = Rhizopoda (14 ± 7 n/l), depicting an almost equal role for these four major groups. The recorded sequence is consistent with the reports of Pandit (1999), but differed from those of Lakiang (1998), who had reported Rotifera > Cladocera; both authors were working in the Himalayan region.

It is noteworthy that copepods were numerically dominant (41.1%–41.8%) in early spring but were succeeded by Cladocera during early summer in the first year of the study. On the other hand, Cladocera was dominant between January and July (30.4%–65.0%) in the first year, while Rhizopoda succeeded this group during the monsoon in both years. Zooplankton exhibited moderate and consistent diversity (2.745 ± 0.293) but a low dominance (0.074 ± 0.046), and an inverse relationship existed between the two ($r = –0.846$). Evenness was high (0.925 ± 0.049) and was positively correlated with species diversity ($r = 0.689$). While no single rotifer was quantitatively dominant, a spring maximum of zooplankton in the second year was mainly the result of a *Daphniopsis* sp. bloom (60 n/l). Similarly, *Tropocyclops* sp. (Copepoda) was found in greater abundance during spring to early summer (3–20 n/l), while *Diaptomus* sp. (Calanoida) only occurred occasionally.

Ecology

Simple correlations computed between abiotic and biotic components indicated the impact of abiotic factors on the planktonic abundance, with the net plankton positively correlating with rainfall ($r = 0.579$) and inversely correlating with transparency ($r = –0.712$) and specific conductivity ($r = –0.505$). Similarly, four of the abiotic factors, i.e., rainfall ($r = 0.535$), transparency ($r = –0.699$), specific conductivity ($r = –0.521$), and total hardness ($r = –0.468$), influenced phytoplankton density significantly, whereas only total hardness ($r = 0.531$) had significant impacts on zooplankton abundance. Rainfall was found to be one of the most important factors in this ecosystem as it significantly influenced six biotic communities, including net plankton, phytoplankton, Chlorophyceae, Cyanophyceae, Dinophyceae, and Rhizopoda.

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